Pricing of Traffic Noise and Exhaust Gases in Road Planning

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Key words traffic, environmental effects, costs, noise, exhaust gases

Abstract

The publication PRICING OF TRAFFIC NOISE AND EXHAUST GASES IN ROAD PLANNING examines the grounds and procedures which can be used to determine costs of damage caused by traffic noise and exhaust gases. The publication is the Report of the Working Group and includes the Proposal of the Working Group.

The Working Group has, based on the studies made, estimated the cost of damage caused by traffic noise and exhaust gases in Finland in 1989. The costs were calculated based on the economic losses caused by different kind of damage, excluding costs caused by climate changes, which were assessed by economic instruments needed to halt the growth of emissions. Owing to the shortage of precise information several assumptions and generalizations had to be used for cost estimation.

The costs of the damage caused by traffic noise and exhaust gases in Finland in 1989 amounted to FIM 4.5 billion, of which exhaust gases accounted for FIM 2.9 billion and noise for FIM 1.6 billion. The costs caused by climate changes accounted for FIM 1.5 billion of the exhaust gas costs.

The total cost of traffic exhaust gases was used to determine the costs caused by different air pollutants. On the basis of this information and the safety coefficient, preliminary unit prices of exhaust gases were calculated. The costs of exhaust gases of vehicles without catalytic converters are on the average 6.5 p/km in road driving and 7.0/km in city driving. Emissions from vehicles with catalytic converters compared with existing vehicles are 70-80% lower, and correspondingly the costs of exhaust gases are also lower. The costs of existing heavy vehicles are on the average 27 p/km in road driving and 32 p/km in city driving. Emissions from heavy vehicles are expected to drop by 50-60% from the present level, and the emission costs of vehicles will also fall.

The costs of damage caused by noise and exhaust gases will not probably affect decisively the profitability of new road projects or their implementation order. In spite of that it is advisable to introduce the pricing system at least for the near future. It can be withdrawn from use later on if the pricing is considered less important. The pricing system will mainly be used for preliminary planning of development projects and for examining the effects of road maintenance programmes.

Preface

The Board of Directors of the Finnish National Road Administration made a decision in principle in 1990, according to which the costs of damage caused by noise and exhaust gases shall be taken into account in social cost calculations of road projects. In 1990 the Finnish National Road Administration established a working group, the task of which was to make a detailed report on the grounds and procedures to be used for the pricing of damage caused by noise and exhaust gases.

The Working Group consisted of Environmental Protection Ombudsman *Benny Hasenson* of the Confederation of Finnish Industries, Senior Inspector *Antero Honkasalo* of the Ministry of the Environment, Special Investigator *Olavi Koskinen* of the Ministry of Transport and Communications, Senior Inspector *Juha Pyötsiä* of the Ministry of Social Affairs and Health, and Assistant Manager *Pauli Velhonoja* (chairman) and Analyst *Mervi Karhula* (secretary) of the Finnish National Road Administration.

According to their task, the Working Group examined effects caused by traffic noise and exhaust gases and their monetary valuation. The Working Group did not deal with monetary valuation of other environmental effects of traffic.

The Working Group had the following studies made, which have been published in the publication series of the Finnish National Road Administration:

The Applicability of the Willingness-to-Pay to the Monetary Valuation of Effects of a Road Project / Helsinki Research Institute on Business Administration (TIEL 3200039) (in Finnish)

The Cost of the Impact of Road Traffic Emissions / Ekono Environmental Technology (TIEL 4000007) (in Finnish).

Assessment of Health and Disamenity Effects Caused by Noise and Exhaust Gases from Road Traffic / Public Health Institute (TIEL 4000010) (in Finnish)

The Technical Development Centre of the Finnish National Road Administration would like to thank all those involved in this work for their notable contribution to the completion of the report.

Helsinki January 1992

Finnish National Road Administration
Technical Development

Contents

1 INTRODUCTION

The social cost assessment of road projects comprises at present construction costs, maintenance and driving costs. The driving costs consist of costs of accidents, time and vehicles. In some road projects effects of the project on employment and trading activities have also been assessed based on costs. Costs of environmental effects have not been included in these assessments.

As traffic noise and exhaust gases continue to increase, it has been suggested on several occasions that costs caused by this damage should also be taken into account when comparing the profitability of projects. When comparing the advantages and disadvantages of different traffic means it has been particularly important to include costs of pollution damage in the assessments.

The Second Parliamentary Traffic Committee proposed in spring 1991 that environmental effects of traffic and their financial value shall be investigated by a comprehensive study based on Finnish conditions /1/. The Committee also required that an extensive social cost study of all large development projects should be made, in which the advantages and disadvantages of the projects will be assessed. The assessment of advantages and disadvantages should also take into account environmental impact. According to the Committee, the advantages and disadvantages should be valued in money as far as possible.

2 STUDIES MADE

2.1 Pricing of noise and exhaust gases abroad

In spring 1990 a study of the methods used by national road administrations of different countries was made to enable estimation of costs caused by environmental effects /2/. Sweden, Denmark and Germany determine costs of traffic noise and exhaust gases in their road projects. The methods used differ significantly from country to country. The methods are based on rough input data on the quality, quantity and costs of damage caused by noise and exhaust gases. Unit prices of the damage have been raised with the increase in knowledge, but there are ten-fold price differences from country to country. In Norway costs of noise are evaluated, but not emission costs. In the UK, they study opportunities to value noise, emissions and other environmental effects in money terms.

Determination of costs of the damage caused by noise and emissions has been based on either the costs of preventive work or the economic losses caused by environmental effects.

The methods used estimate the number of people living near roads and streets and being affected by noise and pollution. Part of the methods assess the effects of emissions on acidification and the ozone quantity on ground level, and the costs caused by them. The estimates do not include costs caused by climate changes.

According to the Swedish National Road Administration, the unit price of a person regarding noise as disturbing is at present SEK 7000/affected person and in Norway NOK 10 100/affected person. Correspondingly, the unit price of a person regarding exhaust gases as disturbing is SEK 15 500/affected person in Sweden. Inhabitants in whose dwelling area noise and concentration levels are higher than the maximum limits are considered to be exposed to exhaust gases and noise. Costs of nitrogen oxides emissions are calculated in Sweden. The unit price of nitrogen oxides is SEK 18 000/t NO_x. All the above costs are annual costs for 1990. Also, the cost of corrosion caused by exhaust gases from heavy vehicles are calculated in population centres in Sweden. The unit price is SEK 0.06-0.14/vehicle-km.

In 1990 an OECD report was made to assess the social cost caused by traffic noise, emissions and accidents /3/. Only a few countries provided information. Costs were evaluated based on either the cost of reducing the drawbacks (using noise barriers, catalytic converters) or the economic losses (medical treatment costs, forest damage).

The average of the total cost of traffic emissions in different countries is 0.4% of GNP. The negative impact of heavy vehicles was assessed to be three-fold compared with passenger cars. The estimates do not include costs caused by climate changes. The average of the cost caused by traffic noise was correspondingly 0.1% of GNP. There are clear cost differences from country to country, which are partly due to different methods in use. For example, in Germany the noise cost is mainly considered to consist of the decrease in the value of estates and, to a less extent, of inconvenience experienced by people. The cost of exhaust gases in the EC countries has been calculated based on the cost of preventive actions. The cost of accidents in road traffic of GNP accounted for 2-2.4% on the average.

Table 1: Estimated social costs caused by traffic exhausts and noise by country at the end of the 1980s /3/.

Country	**% of GNP** *EXHAUST GASES*	*NOISE*
Netherlands	0.15 - 0.2	0.02 - 0.1
Germany	0.4	1.0
France	0.07 - 0.17	0.08 - 0.2
UK	0.16	-
EC countries	0.5	-
Norway	-	0.06

Social costs of traffic noise and exhaust gases in Sweden have been estimated in two separate ways. In the mid-1980s pollution damage was valued in money according to resource losses. The annual cost of exhaust gases were thus SEK 520 - 1 820 million. At present, costs of exhaust gases are mainly estimated based on emissions reduction costs. The Swedish Government has made a decision in principle, according to which, a nitrogen oxides reduction technique for energy production plants is considered profitable with regard to society, if the cost is less than SEK 40/kg NO_x. A corresponding unit price is used for nitrogen oxides emissions from traffic. Unit prices for other traffic emissions (carbon monoxide, hydrocarbons, sulphur dioxide and particles) are determined using toxicity coefficients, which are based on pollution effects. The unit price used for carbon dioxide was SEK 0.25/kg CO_2. Expressed as above, the cost of traffic exhausts totalled SEK 17.2 million in 1989, of which environmental effects accounted for SEK 8.8 billion, health impact SEK 3.8 billion and climate changes SEK 4.7 billion /4/. The cost of exhaust gases of GNP are 1% and carbon dioxide emissions 0.4% of GNP. The cost of traffic noise amounted to SEK 2.8 billion, or 0.2% of GNP. The cost estimates are based on noise abatement costs.

2.2 Principles of monetary valuation of pollution damage

The following principles can be used for monetary valuation of damage caused by traffic noise and exhausts:

- Prevention/ reduction,
  price of achieving the desired emission and noise level; costs caused by noise abatement and technology to reduce exhaust gases

- Willingness to pay,
  how much people and society are willing to pay for cleaner environment, e.g. reduction in emissions and noise

- loss of recourses,
  economic losses caused by emissions and noise. They may be due to lower forest yield, increasing medical care, fouling, etc.

For the report of the Pricing Working Group, two projects analyzed the principles of monetary valuation of environmental effects. In addition, information on costs of reduction in noise and exhaust gases has been collected in Finland.

The Helsinki Research Institute on Business Administration examined the willingness to pay in the pricing of damage caused by noise and exhaust gases /5/. At the same time, the Institute studied the applicability of the willingness to pay to the evaluation of costs of accidents and time.

The social effects of noise and traffic exhausts can be divided into material and non-material effects. **Material benefits** from reduced air pollution are primarily higher output of forestry, agriculture and fishery, release of medical treatment resources, lower production losses caused by diseases and drop in demand for material repairs. The value of material benefits should be calculated by resource losses.

Non-material benefits as a result of reduced air and noise pollution are increased convenience and comfort, preservation of historic buildings and monuments. The monetary value of these benefits, because of their subjective nature, can primarily be assessed by the methods based on the willingness to pay /5/.

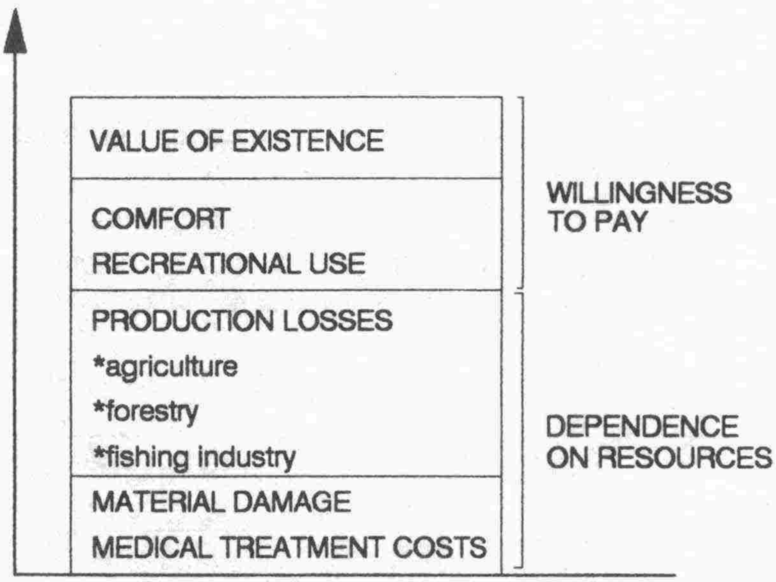


Figure 1: Principle of monetary valuation of environmental effects

The method based on the willingness to pay has been used to some extent for estimating costs of environmental effects. No studies of solely road traffic have been made. People in Germany, Norway and the Netherlands have been asked about their willingness to pay for the improved air quality in a certain area. Traffic has been one of the factors affecting the air quality.

Ekono Environmental Technology made a study of monetary valuation of traffic exhausts by resource losses. The study assessed only costs of material effects caused by air pollution. The study also estimated costs caused by traffic exhausts in Finland in 1989 using the information available about air pollution effects /6/.

Of the damage caused by traffic exhausts, the study dealt with corrosion, fouling, health impacts and crop and forest yield losses. Mainly the dose-response data of the foreign studies were used to assess the environmental damage caused by air pollutants. The quantity of the damage caused by Finnish traffic exhausts was assessed by emissions, concentrations and deposition of pollutants. The cost of damage was calculated based on the Finnish 1989 cost level.

The cost caused by traffic emissions, according to the calculation made, amounted to some FIM 1.2 million in 1989 (see appendix 1) /6/. Several assumptions and generalizations were necessary to make the calculation, as a result of which it is a rough estimate of exhaust gas costs. The Ekono calculations do not include the cost of global effects and disamenity effects. To estimate costs, sensitivity analyses were made and their effects on total costs were studied.

The study calculated the share of different emission components of the total costs, including nitrogen oxides, hydrocarbons, sulphur dioxide, particles and ozone generated from emissions. This information is utilized for estimating unit costs of emissions. Figure 2 shows the collected input data for cost calculation. Some of these factors have had to be used to determine input data. For example, when defining corrosion damage the quantity of material has been calculated based on the number of inhabitants in population centres.

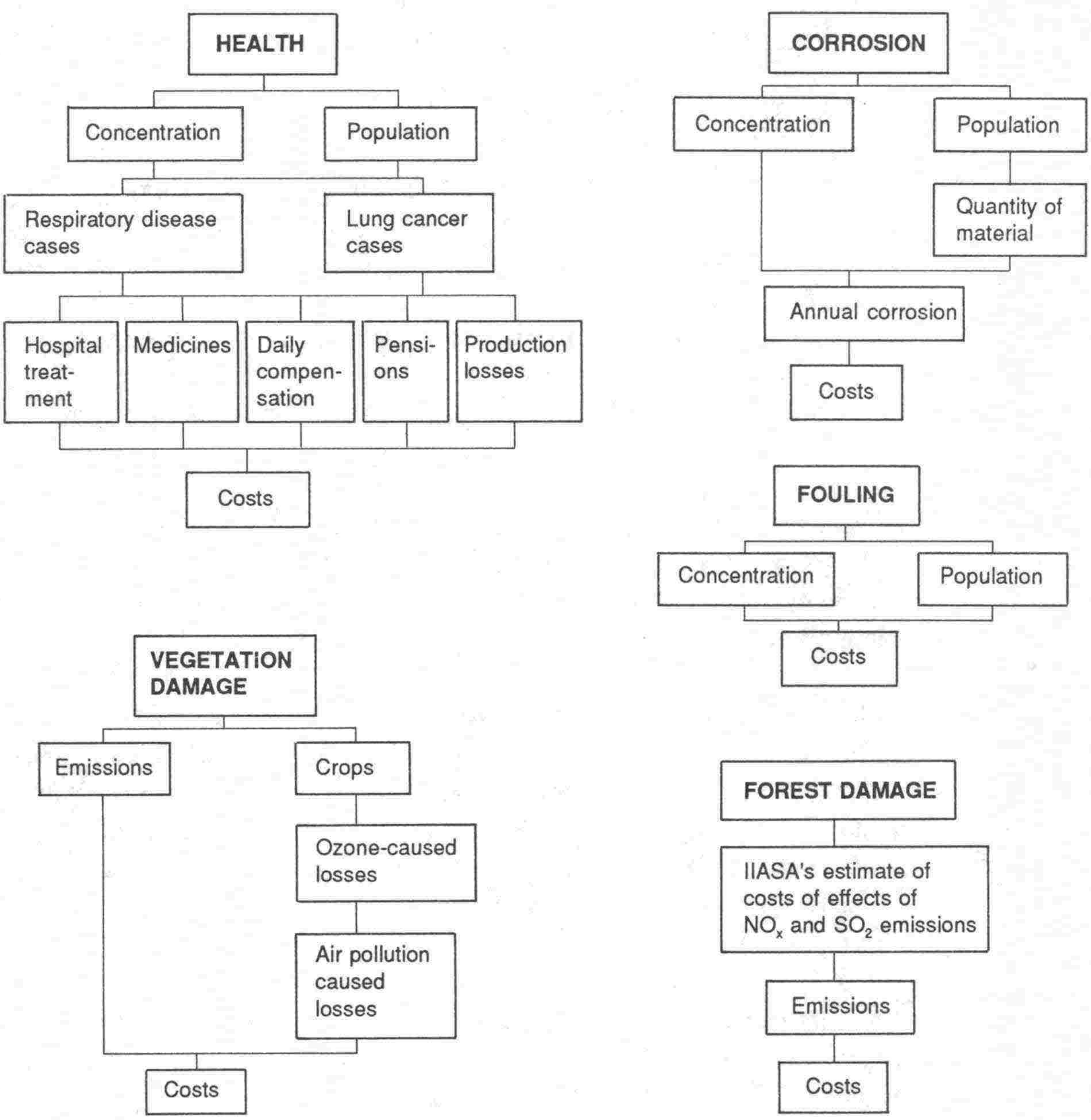


Figure 2: Input data used to assess the extent and cost of the damage caused by exhaust gases.

2.3 Methods to determine pollution damage

A uniform method to assess environmental effects is preferred when planning road projects. This method includes assessing the impact of a road project on, for example, noise levels, emissions, concentrations and the number of people affected by the damage. Effects of noise and emissions are then assessed qualitatively. The qualitative assessment inspects the significance of the impact of the project for the changes in the state of the environment. The effects of the road project alternatives are compared and assessed to find out how different alternatives will meet the environmental requirements set on the project. The impact assessments made during the planning give input data for estimating costs of noise and exhaust gases.

Emissions from the road projects are calculated using the Kehar software or corresponding models. Models designed for emissions calculation have been developed so that driving conditions and the technical standard of vehicles can be taken into account in calculations. To calculate emission-caused concentrations, models for both streets and roads are available /7/. Guidelines for calculating noise levels have been given to designers /8/.

The Laboratory of Urban Planning and Building Design of the Technical Research Centre of Finland (VTT) was assigned by the Finnish National Road Administration to inspect a method which would enable estimation of numbers of inhabitants in noise areas near existing roads and roads under planning. Numbers of inhabitants in the used land areas are calculated with the help of the data from the Population Register Centre and numbers of inhabitants in future land areas by master plans. Guidelines for using the method will be completed in spring 1992.

The harmful effects of traffic noise comprise lost sleep and rest, disturbed discussion and disturbed work that demands concentration and irritation resulting from these. Harmful effects of exhaust gases on people are different kinds of diseases and discomfort. Discomfort is caused by the smell of exhaust gases, lower visibility and fouling.

The Norwegian study inspected the amount of the damage affecting people using different exhaust gas concentrations. Some 25% of those interviewed considered exhaust gases very disturbing and 55% little disturbing with a carbon monoxide concentration of 3 mg/m^3 /9/. Carbon monoxide was used as an indicator to describe concentrations of different compounds of exhaust gases. Norwegian studies have also inspected, based on questionnaires, the disturbance of different noise levels at the end of the 1980s /10/.

Table 2: Number of people considering noise disturbing at different noise levels according to the Norwegian study /10/.

Noise level L_{Aeg} day	**Disturbs markedly** (%)	**Disturbs little** (%)	**Does not disturb** (%)
< 55 dB	10	20	70
55-65 dB	33	33	33
> 65 dB	50	25	25

The Public Health Institute studied the impact of exhaust gases and noise on health, assessed the methods to determine health effects caused by noise and pollution used in various countries, and designed a draft model applicable to Finnish conditions /11/.

Foreign calculation models calculate impurity concentrations and noise levels in the vicinity of the traffic route and assess the number of people affected by traffic pollution. The maximum values of air quality and noise in each country have been used as limit levels for determining the damage.

The Public Health Institute suggests that for studying the impact of noise in road projects hourly inspection would be used, which would take into account, for example, equivalent levels, maximum noise levels, number of noise events, frequency and duration. The maximum noise level and the number of noise events, in particular in the nighttime, are often more important indicators than an equivalent level. The report also says that if in different project alternatives there are no great differences in the composition of traffic it is possible to use only the equivalent level to describe the amount of damage if the levels are calibrated with each other /11/.

The Public Health Institute proposes that estimation of nitrogen dioxide and carbon monoxide concentrations should be included in the appraisal of health and comfort effects caused by exhaust gases. Because of Finland's cold climate, the common impact of pollutants and reduced comfort aspects, the lowest limit for determining the damage should in that case be the eight-hour concentration of carbon monoxide, which is 1-3 mg/m^3. In that case carbon monoxide describes the common impact of all compounds /11/.

3 THE COST OF NOISE AND EMISSIONS

3.1 The cost of exhaust gases and noise nuisance in 1989

The Working Group on Pricing has, on the basis of the studies made, estimated the cost of traffic noise and exhausts in Finland in 1989. The cost estimate of damage was based on the economic losses, excluding the cost of climate changes. The cost of climate changes has been assessed by the charges and fees needed to stop the growth of carbon dioxide emissions. Several assumptions and generalizations were necessary to estimate costs.

According to the estimate of the Working Group on Pricing, the costs of the impact of noise and traffic exhausts in 1989 were FIM 4.5 billion, of which exhaust gases accounted for FIM 2.9 billion and noise for FIM 1.6 billion. The expenditure includes the cost of both street and road traffic.

Table 3: Cost estimate of damage caused by traffic exhausts and noise in Finland in 1989.

EXHAUST GASES	**FIM mill.**
Diseases	260
Fouling	410
Corrosion	40
Forestry: stock loss	220
Crop yield loss	220
Comfort*	300
Climate change**	1 500
TOTAL	2 900
NOISE	
Comfort	1 600
TOTAL	**4 500**

* Working Group's own estimate

**Estimated by economic instruments needed to stop the growth of CO_2 emissions /13/

Finnish gross domestic product in 1989 was FIM 495 billion. The cost of exhaust gases accounted for 0.3% of GDP and the cost of carbon dioxide emissions also for 0.3% of GDP. According to the OECD study made in 1990, the exhaust gas costs of different countries were on the average 0.4% of GDP. The OECD study does not include climate changes. With regard to exhaust gases, the estimate of the Working Group on Pricing corresponds to an average level.

The cost of damage caused by noise was 0.3% of GDP. According to the OECD study, the cost was on the average 0.1% of GDP and the fluctuation range was large (cf. Table 1). The differences are primarily due to the differing principles used for the calculation. The cost of damage caused by noise in Finland is on the same level as in Sweden.

The driving costs of road and street traffic in 1989 amounted to FIM 75 billion. The costs have been calculated based on the 1990 unit values of the Finnish National Road Administration and on the number of accidents and the traffic flow in 1989. The time costs were FIM 30 billion, the costs of vehicles FIM 35 billion and the costs of accidents FIM 9.5 billion. The cost of damage caused by noise and exhaust gases is FIM 4.5 billion, or 6% of the driving costs. In 1989 the vehicle mileage on public roads and streets totalled 39 billion kilometres, and the noise and exhaust gas cost per driving kilometre was thus 11 p/km on the average.

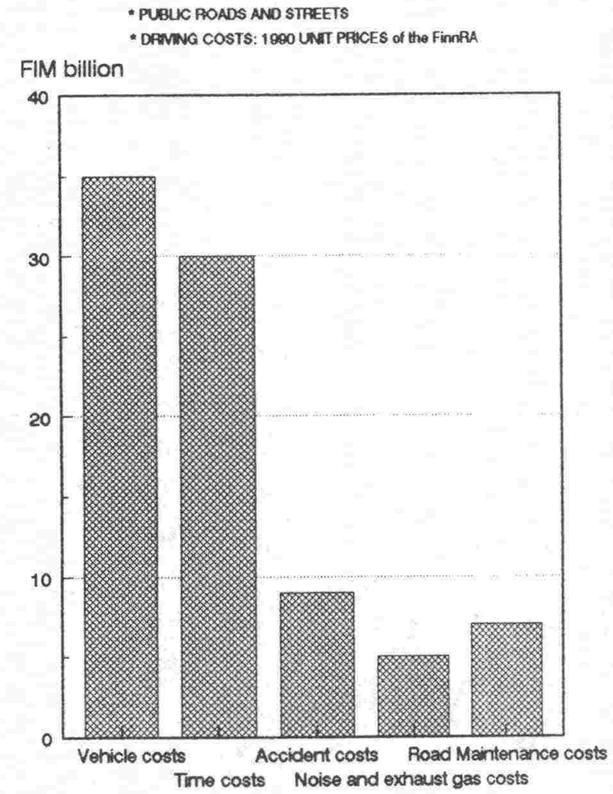


Figure 3: Driving and environmental costs, and road maintenance costs in 1989 (public roads and streets).

3.2 Methods used to estimate the cost of damage caused by exhaust gases and noise

Foreign literature provided a lot of information about the effects of air pollutants and noise nuisance and about determination of the cost of damage by economic losses. Several assumptions were necessary for estimating the extent and the cost of damage caused by exhaust gases. The assumptions used in the estimates and the shortcomings of the information available are reported separately /6/.

The Working Group estimated the cost of disamenity effects caused by exhaust gases. It was not possible to estimate the cost of climate change by resource losses. To determine the cost and damage caused by traffic noise the Working Group used the corresponding principle as in the study made for the Ministry of Traffic in 1988 /12/.

Air impurity concentrations generally, except in town centres, remained under the air quality limits based on health aspects. However, exhaust gases together with other air pollutants increase the risk to become ill. When estimating the cost of road traffic, it was assumed that exhaust gases cause 80 lung cancer cases annually. In addition, it was assumed that the share of air pollutants of the number of cases of respiratory diseases is 25%. The share of road traffic of the total cost of respiratory diseases caused by air pollution is in turn about one half. The cost taken into account include hospital and non-hospital care costs, medicine, daily sickness allowances, disability pensions and production loss costs of employers. The cost of **diseases** caused by exhaust gases was estimated at FIM 260 million in 1989 /6/. The estimate does not include welfare losses caused by diseases or a possible death.

Effects of **fouling and corrosion** caused by exhaust gases occur in population centres and towns. The total cost of this damage in 1989 was FIM 450 million /6/. The expenses are estimated based on material replacement, painting and cleaning costs. Estimation of fouling costs is based on increased cleaning times in households. The damage caused by fouling is of similar type as disamenity effects.

The cost resulting from **forest damage and forest yield loss** is estimated on the basis of the calculations made by the international research institute IIASA. The cost estimate is based on the assumption that 70% of the damage caused by air pollution is due to sulphur and nitrogen deposition and 30% to other air impurities /6/.

The cost of road traffic is estimated based on the information about exhaust gas deposition. The value of forest losses was FIM 220 million in 1989.

A Swedish study of ozone-caused crop losses of cultivated plants was used to assess **crop losses** caused by air pollution. In addition, it was assumed that ozone causes half of the crop losses, that is, total costs are twice as high as the cost caused by ozone /6/. Crop losses caused by road traffic amounted to FIM 220 million in 1989.

According to the Report of the Carbon Dioxide Committee /13/ published in June 1991, a tax of FIM 150/carbon dioxide tonne (36 p/litre of petrol, 39 p /litre of diesel oil) might be sufficient to stop the growth of carbon dioxide emissions. This requires that all industrialized countries would pursue a similar policy. The Committee further stresses that social costs as production losses and decreased income would be lower than the cost caused by the tax. The carbon dioxide emissions of road traffic in 1989 were 10 million tonnes, so that the cost caused by **climate changes** amounted to FIM 1 500 million. The cost describes partly the society's willingness to pay. So, the principles differ from the principles of 'monetarizing' of other damage in this study.

Costs of **disamenity effects (discomfort)** caused by exhaust gases can mainly be estimated by interviewing people. No results of this kind of research are available in Finland or abroad. However, Gallup polls about disturbance of exhaust gases were carried out in Norway in the mid-1980s, and these results clearly show the discomfort of exhaust gases /9/. The Working Group on Pricing attempted to determine an order of magnitude for discomfort effects and arrived at an estimate of FIM 300 million. The estimate is based on medical treatment costs and on the view that the discomfort effects of exhaust gases are of the same of magnitude as the health impact.

Noise effects of traffic road are primarily due to greater discomfort. It is very difficult to separate the cost of health impact and the cost of disamenity effects. To estimate total costs caused by noise, it is necessary to know the number of people living in the traffic noise area. According to the study made by the Technical Research Centre of Finland by order of the Ministry of Transport and Communications in 1988, 840 000 people lived in areas with over 55 dB noise levels /12/. The cost of noise is estimated based on the number of people affected by noise. The number of people affected at different noise levels in the estimate of the Working Group is based on the interviews made in Norway at the end of the 1980s /10/. Damage is assumed to occur when man considers noise markedly disturbing (cf. Table 2). The number of people affected at a noise level of 55-65 dB has been raised compared with the study made by order of the Ministry of Traffic. In that study the number of people affected was based on the estimate of the Swedish National Road Administration.

Table 4. Estimate of number of people living in noise areas of public roads and streets and of people considering noise disturbing in 1989 /10,12/.

dB	People living in noise areas	People considering noise disturbing	
		Share	*Number*
55-65	588 000	33 %	194 000
65-70	210 000	50 %	105 000
70-	42 000	100 %	42 000
Total	**840 000**		**341 000**

Disamenity effects caused by noise can be valued in money terms mainly using the willingness to pay method. No results of this kind of studies are available and for that reason, the Working Group decided to use in their cost estimation the principle of the study made by order of the Ministry of Transport and Communications /12/. The damage caused by noise was assessed in the study using the duration of noise factor and the time unit values used by the FinnRA. Noise was assumed to affect 15 times a day and its duration was assumed to be 15 minutes. Part of the noise is expected to occur during working hours and part during leisure time, and the corresponding time unit prices were used to estimate costs. So, an annual cost of FIM 4900 is caused to those suffering from noise. The cost has been calculated by using the time unit values of the the Finnish National Road Administration for 1990. The unit price of noise is at a corresponding level as the unit prices used in Norway and Sweden. The unit price in Sweden has been calculated based on noise abatement costs.

Total costs of noise calculated on the basis of the damage caused by noise is FIM 1600 million. In that case it is assumed that the number of people living in the noise areas along streets and public roads is 840 000 and the number of people affected by noise is 341 000.

The Report on Disturbing Noise from Public Roads made by order of the Finnish National Road Administration in 1991 estimates that some 350 000 people live in the 55 dB noise areas along public roads /14/. The order of magnitude of this estimate is equal to the one made in 1988 to the Ministry of Transport and Communications. The share of public roads was not calculated separately in this study. The number of people affected by noise and living along public roads is, according to the principles presented by the Working Group on Pricing, 125 000 and the cost of the damage caused by noise FIM 620 million.

4 PRICING PRINCIPLES IN ROAD PLANNING

The damage caused by noise and exhaust gases should be priced in road planning on the basis of economic losses and people's willingness to pay. The willingness to pay should be used to value in money terms disamenity effects caused by noise and exhaust gases. No results of people's willingness to pay are available in Finland or other countries, so that the estimate of the Working Group on Pricing is used to monetarize disamenity effects caused by noise and exhaust gases. Studies of the willingness to pay should be carried out in the future.

The estimate of the cost of noise and exhaust gases is based on the damage caused by the present load. Changes in the environment and more accurate information about the reasons for environmental pollution will require regular checking of calculation methods and unit prices.

4.1 Exhaust gases

In connection with the environmental impact assessment for a road project, emissions from traffic and emission-caused concentrations are examined in the vicinity of the road. Emissions of carbon monoxide, nitrogen oxides, hydrocarbons, particles and carbon dioxide are calculated. Concentrations of nitrogen dioxide and carbon monoxide are estimated. The calculations of emissions and concentrations include the reduction in emissions from vehicles in the future. So, emissions will fall from their present levels in spite of the growth of traffic volumes.

The damage caused by exhaust gases is essentially affected by the environment in which exhaust gases are emitted. **The Working Group on Pricing arrived at the method in which the pricing of exhaust gases in road projects is based on the quantities of emissions.** In connection with the environmental impact assessment the effect of emissions in different environments is taken into account. With the ever-increasing amount of information, the pricing method must, however, be reassessed and the effect of different environments on the cost caused by exhaust gases must be studied.

The carbon monoxide and nitrogen dioxide concentrations will clearly be lower, even with high traffic volumes, than the present air quality limits that are based on health aspects. The concentrations will fall following the development of vehicle technology.

The Public Health Institute proposed that the determination limit of an disamenity effect would be a carbon monoxide concentration of 1-3 mg/m^3. In that case, the carbon monoxide concentration also describes the effect of other compounds. In the vicinity of the road route the number of people affected by exhaust gases will be rather small in the future (with these figures, too). These concentrations would primarily affect people who live in the immediate vicinity of the main roads in the largest cities. There would be no significant differences in the numbers of those affected by exhaust gases between different alternatives.

Total costs of the damage caused by road traffic can be divided on the basis of the studies of different air pollutants /6/. Ozone is formed in the air from nitrogen oxides and hydrocarbons. Ozone emissions cannot be estimated in quantity. The cost of ozone effects caused by traffic exhausts (FIM 210 million) has therefore been divided among nitrogen oxides and hydrocarbons. The cost of disamenity effects (FIM 300 million) has been divided among nitrogen oxides, hydrocarbons and particles. Table 5 shows the costs of different types of emissions from traffic in 1989. The cost of the damage caused by carbon monoxide and sulphur dioxide are so minor that they do not essentially affect the total costs. Using this information it is possible to determine the unit prices of different emission components (FIM/t) or vehicle specific costs (p/vehicle-km).

Table 5. Traffic emissions and estimate of cost of different types of emissions in Finland in 1989.

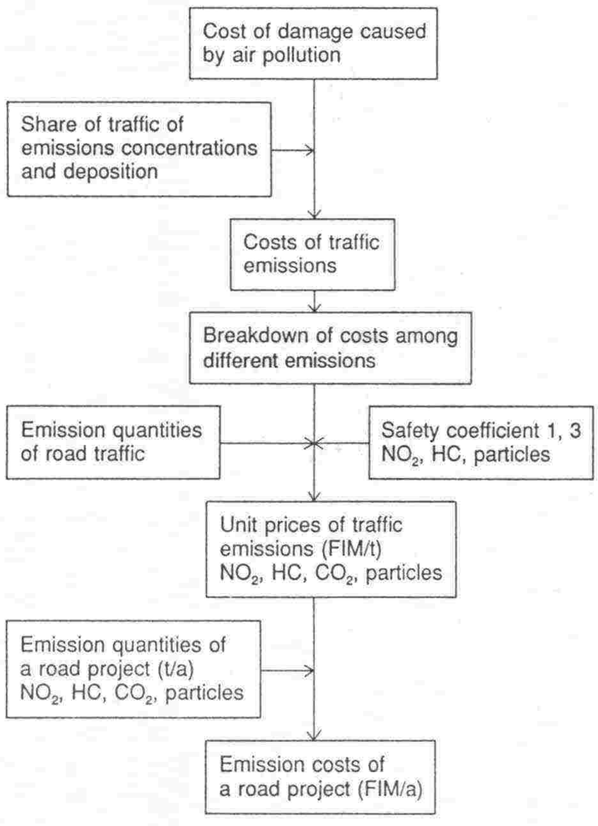
	Nitrogen oxides FIM mill./a	**Hydro-carbons**	**Particles**	**Carbon dioxide**
Diseases	68	32	160	
Fouling			410	
Corrosion	21			
Forests	114	57	27	
Fields	112	83	13	
Comfort	100	100	100	
Climate change				1500
COST OF TRAFFIC 1989				
FIM mill./a	415	272	710	1500
TRAFFIC EMISSIONS 1989 t/a				
	123 000	40 700	11 600	10 000 000

When estimating costs of exhaust gases, the goal was to calculate the cost of as many effects as possible. However, there are factors which are not yet known or their effects are minor. For this reason, **the Working Group on Pricing decided to use a safety coefficient of 1.3 for determining unit prices. The coefficient is used in the unit prices of nitrogen oxides, hydrocarbons and particles.**

The cost of different types of emissions, the safety coefficient and the specific emissions from vehicles described above are the basis for determining the preliminary average unit prices of light and heavy vehicles for road planning. The costs of existing vehicles without catalytic converters are on the average 6.5 p/km in road driving and 7.0 p/km in city driving. The emissions from vehicles with catalytic converters compared with existing vehicles are 70-80% lower, and consequently, the costs are also lower. The costs of existing heavy vehicles are on the average 27 p/km in road driving and 32 p/km in city driving. The emissions and costs of heavy vehicles will be 50-60% lower in the future.

More detailed guidelines for calculating the cost of emissions and the final unit prices will be determined in spring 1992. Figure 4 presents how the costs of exhaust gases are estimated in road planning.

Figure 4: Principle of estimating costs of exhaust gas emissions from road traffic in road planning.



4.2 Noise

Several disturbances caused by noise, such as lost sleep, are dependent on the noise level that prevails inside the houses. In the nighttime especially, the maximum noise level and the number of noise events are more important indicators than the equivalent level. These values depend, for example, on building insulation, open windows, the volume and speed of heavy traffic in the night. Calculation of these noise values requires significantly more precise input data on the composition of traffic than usually available. The composition of traffic does not often show marked differences in different alternatives of road projects.

The equivalent level of outside noise in the daytime can be calculated on uniform grounds in road planning. The studies also show a rather close relationship between the equivalent level and the significance of noise experienced by inhabitants irrespective of what sort of noise actually disturb the inhabitants.

The Working Group on Pricing decided to use the pricing method, in which the damage in the vicinity of roads is calculated by the equivalent level of outside noise during the daytime. The cost of noise effects is calculated by the number of inhabitants affected by noise and the noise unit price.

In road projects the number of people living in the noise areas are estimated by the equivalent levels of daytime noise (from 7 a.m. to 10 p.m.). The number of people affected by noise varies at different noise levels. Damage caused by noise is calculated to affect as from 55 dB and the share of those who consider noise as disturbing is calculated by the following principles:
at a noise level of 55-65 dB the share of people considering noise as disturbing is 33%; at a noise level of 65-70 dB the share is 50% and as from a noise level of over 70 dB all people consider noise as disturbing.

The damage caused by noise has been assessed by the duration of noise and the time unit prices used by the Finnish National Road Administration. Part of the damage takes place during working hours and part during the leisure time. **The used unit price of the damage caused by noise is FIM 5000/person affected at the 1991 price level.**

The Working Group on Pricing decided to use the Norwegian estimates of noise damage. Corresponding studies should also be made in Finland to assess noise effects more accurately. Willingness to pay studies are needed to specify the unit price of noise.

4.3 Social cost calculations

Social cost studies of road projects provide information about the advantages and disadvantages of the project, evaluation of various alternatives and the profitability of the whole project. The social observation method requires in principle assessment of all indirect and direct advantages and disadvantages and their valuation in money terms. The costs, advantages and disadvantages can be divided into the following groups:

- costs of road maintenance organization
- costs of vehicles, time and accidents
- environmental costs; noise and exhaust gases
- indirect costs; economy, employment

The necessity studies and general plans of road projects determine the necessity of the project and investigate which alternative is the most profitable. The effects of the alternatives according to the forecasted traffic volumes are compared with the present situation (alternative 0) and with the existing road network with minor improvements (alternative 0+).

The advantages and disadvantages of a road project are taken into account from a certain calculation period. The observation period is usually 20-30 years from the expected completion of the project. A discount rate is used to discount the costs incurred at different times and the cost of the advantages and disadvantages to a common time period. An interest rate of 6 per cent is usually used in road projects and all costs are discounted with the same interest rate.

The cost of noise and exhaust gases in road projects are calculated using the number of people affected by noise and the quantities of exhausts which are calculated in connection with the environmental impact assessment of road projects. The costs are compared with the situation in which the project is not implemented, but traffic increases according to the forecast. The cost of noise and exhaust gases is included in the cost/benefit calculations with the same principles as the driving costs. The environmental costs caused by the project are shown in the calculations as a separate group.

Pricing of noise and exhaust gases was tested in two different road projects: Lappeenranta-Imatra Motorway Project and The Improvement Project of Highway 17 between Kuopio and Riistavesi. Tables 6 and 7 include some financial indicators of the projects in greater detail. The calculations were made according to the principles referred to.

The improvement of Highway 6 Lappeenranta-Imatra was studied in three different alternatives. Alternatives P and JA describe the construction of a new motorway from Lappeenranta to Imatra and alternative 0+ the improvement of the existing highway by mainly building new highway grade separations. In alternative P the motorway would run through the population centre of Joutseno and in alternative JA it would pass the population centre. The traffic volume in the area under planning in 2010 would be 12,000-18,000 vehicles a day. The improvement of the existing highway or construction of a new motorway would cover 48 kilometres. The speed limit in the motorway alternatives would be 120 km/h and in the improvement alternative 100 km/h. The additional costs caused by the environment would be 6-7% of the cost savings in the motorway alternatives.

Table 6. Improvement of Highway 6 Lappeenranta-Imatra. Investment (FIM mill.), cost savings in 2010 (FIM mill./a) and cost/benefit ratio (Savings marked with plus, additional cost marked with minus).

Alternative	0+	P	JA
Investment FIM mill.	254	945	863
Cost/Saving		FIM mill./a	
Time	38.7	116.7	110.7
Vehicles	15.8	-58.3	-56.9
Accidents	3.8	38.7	36.8
Maintenance	-2.5	-8.9	-8.1
Savings total	55.8	88.2	82.5
Cost/benefit ratio	2.5	1.1	1.1
Noise	0	-1.1	-0.9
Exhaust gases	0.6	-4.5	-4.4
Savings total	56.4	82.6	77.2
Cost/benefit ratio	2.5	1.0	1.0

The improvement of highways 5 and 17 between Kuopio and Riistavesi has also been studied in three alternatives. Approx. 22 km of new road would be built in alternatives C and E. In alternative E a new bridge would be built to cross Kallavesi in Kuopio and part of the road would be in a tunnel. In alternative AK some 25 km of the existing road would be improved. The traffic volume in the area under planning would be 6000-14000 vehicles a day, and the speed limit would be 80-100 km/h.

Table 7: Improvement of highways 5 and 17 between Kuopio and Riistavesi. Investment (FIM mill.), cost savings in 2010 (FIM mill./a) and cost/benefit ratio. (Savings marked with plus, additional cost marked with minus).

Alternative	AK	C	E
Investment FIM mill.	304.4	332.3	446.1
Cost/Saving		FIM mill./a	
Time	4.2	4.4	9.1
Vehicle	0.8	3.1	13.0
Accidents	0.9	-0.5	2.1
Maintenance	0.0	-0.4	-0.2
Savings total	5.9	6.6	24.0
Cost/benefit ratio	0.3	0.3	0.8
Noise	-0.1	0.4	0.4
Exhaust gases	-0.6	-0.3	1.0
Savings total	5.2	6.7	25.4
Cost/benefit ratio	0.3	0.3	0.9

The effect of the cost of noise and exhaust gases on the cost/benefit ratio in the two above road projects was small. The significance may be greater, for example, in projects in which a substantial part of the traffic flow transfers to the bypass road. It is necessary to obtain additional experience of the effect of the cost of the damage caused by noise and exhaust gases on the profitability of road projects through several types of projects. Pricing can be withdrawn from use if it is considered less important. Pricing will mainly be used for pre-engineering of development projects and for examining the effects of road maintenance programmes.

5 CONCLUSION AND PROPOSAL OF THE WORKING GROUP

The Working Group on Pricing, based on the studies made, has estimated the cost of the damage caused by traffic noise and exhausts in Finland in 1989. The cost was estimated by economic losses caused by different kinds of damage excluding climate change. The cost of climate change was estimated based on the economic instruments needed to stop the growth of emissions. Several assumptions and generalizations were necessary for estimating costs.

According to the Working Group, the cost of the damage caused by traffic noise and exhausts in 1989 amounted to FIM 4.5 billion, of which exhaust gases accounted for FIM 2.9 billion and noise for FIM 1.6 billion. The share of the cost caused by climate changes of the cost of exhaust gases was FIM 1.5 billion.

The Working Group on Pricing proposes the following to be taken into account in road planning:

- The cost of noise and exhaust gases should be taken into account in evaluations of social costs.

- Environmental impact assessments should consider traffic noise and exhaust gases as quantities and the damage caused by them as a qualitative value.

- The damage caused by noise and exhaust gases should be valued in money terms by resource losses, except for climate climate. Climate change should be valued in money terms using the fees needed to halt the growth of carbon dioxide emissions.

- Resource losses should be used to value in money terms exhaust-gas-caused diseases, corrosion, forest damage, crop losses and disamenity effects of noise and exhaust gases.

- The willingness to pay method should be used to value in money terms disamenity effecs of noise and exhaust gases. With increasing information, monetary valuation should be specified in this respect.

- Costs caused by emissions should be estimated by emission quantities. Unit prices of emissions should be determined by the total cost caused by exhaust gases and carbon dioxide emissions from traffic in 1989. Unit prices should be determined for nitrogen oxides, hydrocarbons, particles and carbon dioxide. A safety coefficient of 1.3 for all compounds except carbon dioxide should be used to determine unit prices.

- Noise costs should be evaluated by the number of inhabitants affected by noise. The number of people living in the noise areas should be estimated by the equivalent levels of outside noise (from 7 a.m. to 22 p.m.). The number of people affected by noise should be estimated based on the following: at noise levels of 55-65 dB the share of those affected by noise is 33%; at noise levels of 65-70 dB it is 50%, and as from a noise level of 70 dB the share is 100 %. The unit price used for a person affected by noise should be FIM 5000/person exposed/a.

- Pricing method for noise and exhaust gases and unit prices should be checked regularly.

- Further studies should deal with the amount of damage people are exposed to at different noise and concentration levels. Studies of people's willingness to pay for cleaner environment should be carried out to specify unit prices.

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EKONO ENVIRONMENTAL TECHNOLOGY

The cost of the impact of road traffic emissions

1. INTRODUCTION

This report is a summary of the survey "Tieliikenteen päästöjen haittojen kustannukset" (TIEL 40000007) (The cost of the impact of road traffic emissions) carried out by Ekono Environmental Technology. The objective of the survey was to make possible for the Finnish National Road Administration to consider impacts of emissions expressed in monetary terms in road planning parallel with other factors affecting the project. Thus, the possibilities to use the economic value of damage caused by emissions as a basis for unit prices of emissions have been surveyed.

The study surveys emissions from road traffic, their share of the deposition on forest and agricultural areas as well as their share of the concentrations of impurities in communities. The study includes all the most important emission components, i.e. nitrogen oxides, hydrocarbons, sulphur dioxide, particulate matter, carbon monoxide, lead and carbon dioxide. In addition, the ozone formed in the atmosphere is included. Valued impacts are corrosion, fouling and soiling, health effects, forest damage and loss of crops.

The valuation method used is indirect valuation, in which a dose-response relationship between the impurity and its effects is searched for. The economic value of the impact is calculated using costs of renewal, replacement, compensation and alternative costs.

2. THE EMISSIONS FROM ROAD TRAFFIC

This chapter presents data on road traffic emissions and their share of deposition and concentrations needed for calculating costs.

In 1989 the total road traffic in Finland amounted to about 38.7 billion vehicle kilometres. Table 2.1 shows the amount of traffic and the number of vehicles in 1989.

Table 2.1. The amount of traffic and the number of vehicles in 1989, million kilometres /17/.

Vehicle	Public roads	Streets mill. vehicle-km	Total	Number
Private cars	22 640	10 040	32 680	1 940 000
Vans	1 870	810	2 680	180 000
Buses	470	200	670	9 000
Trucks	2 170	510	2 680	53 000
Total	27 150	11 560	38 710	2 182 000

Table 2.2 shows the share of road traffic of total emissions in Finland in 1987 and 1989. The data is collected from different sources.

Table 2.2. The share of road traffic of total emissions in Finland in 1987 and 1989 (Pönkä [15], pp. 652, 659, The Ministry of the Environment [11], pp. 91-92, Report of the Parliamentary Traffic Committee [20], p. 85).

Emission type	1987 Share	1987 Amount	1989 Share	1989 Amount
SO_2	2%	6000 t	2%	5400 t
NO_x	51%	112000 t	55%	123000 t
CO	69%	285000 t	approx. 90%	308000 t
CO_2	* 14%	9800000 t	> 10%	10000000 t
HC	20%	38000 t	approx. 20%	40700 t
Particles	** 10%	11000 t	approx. 10%	11600 t
Pb	70%	320 t	..	300 t

.. : Data not available
* : Report of the Parliamentary Traffic Committee [20], p. 85
** : The emissions of particulate matter that originates from road paving and gravel roads are estimated to be about 260 000 tonnes a year

Table 2.3 presents road traffic emissions in streets and public roads in 1989. The figures are calculated with the LIISA II data system developed by the Technical Research Centre of Finland VTT /22/.

Table 2.3. Road traffic emissions in streets and public roads in 1989, t/a /22/.

	SO_x	NO_x	CO	HC	Pb	Particles
Streets	906	22454	183547	21157	86	1947
Public roads	3506	94512	121070	18730	224	8338
Total	4411	116966	304617	39888	310	10285
Amount of traffic (mill. km/year)		Streets 9701			Public roads 26029	

Table 2.4. The share of emissions of different type of vehicles in 1987,% /20/.

Type of vehicle	SO_x	NO_x	CO	HC	CO_2	Pb	Particles
Private cars	49	48	89	73	56	97	43
Vans	8	3	4	7	9	3	10
Buses	7	11	1	5	8	0	12
Lorries	36	38	6	15	27	0	35
Road traffic	2	49	92	16	14	80	10

Deposition

The figures describing the domestic shares of pollutants in Table 2.5 have been used in calculations (SO_2 and NO_x, VTT /7/). Except sulphur and nitrogen deposition, all other road traffic emissions are included. The share of domestic sources concerning ozone formation in the lower atmosphere has been estimated at about 20% in Sweden, /3/ and /16/. Particles and hydrocarbons are assumed to be from domestic sources only. The table also presents the share of road traffic of the pollutants under survey. These shares have been used to estimate to which extent road traffic is responsible for the deposition. The data in the last column has been used to calculate the value of forest damage and crop losses due to road traffic pollution.

Table 2.5. The share of domestic sources of total deposition, the share of road traffic of total emissions and the share of road traffic of deposition (VTT, /7/, Ekono's estimate).

Pollutant	From Finnish sources %	Share of traffic of emissions %	Share of traffic of deposition %
SO_2	25	2	0.5
NO_x	20	55	11
Particles	100	10	10
HC	100	20	20
CO	90	90	81
Pb	100	55	55
O_3	* 20	* 50	* 10

* : This is no emission component, and no absolute figure can therefore be given. The figures in the columns "From Finnish sources" and "Share of traffic of emissions" are estimates of the share of ozone formation. When ozone is formed, especially nitrogen oxides and hydrocarbons play a central role.

Concentrations

When calculating costs of health impacts, it has been assumed that these impacts occur in communities only. Additionally it has been assumed that the air quality in all urban areas in Finland can be compared with the average air quality in the Great Helsinki Area (not in the centre of Helsinki, but in the suburbs, such as Tapiola and Tikkurila). The share of road traffic of total concentrations (annual mean values) of different pollutants have been presented in the following table:

Table 2.6. Measured annual mean concentrations in the Great Helsinki Area and estimate of the share of road traffic of these concentrations /1/, /6/, /9/, /10/, /15/.

Pollutant	Total concentration $\mu g/m^3$	Share of traffic %	Share of traffic $\mu g/m^3$
SO_2	10 - 20	5	0.5 - 1
NO_x	30 - 60	60	18 - 36
Particles	30 - 50	5	1.5 - 2,5
		* 75	* 23 - 38
HC	1000 - 2000	90	900 - 1800
CO	200 - 400	90	180 - 360
Pb	0.1	100	0.1
O_3	40 - 50	** 0	** 0

* : Particulate matter that originate from vehicles (slitage on breakes and wheels) and dust that traffic lifts from the roads
**: In the city no net production of ozone has been identified, emissions from road traffic seem to act as an ozone sink

Later on we will also need to know the share of the Finnish population living in urban areas.

In 1985 (November 17) 2 703 526 people lived in Finnish towns and cities and 1 039 751 people lived in other urban areas (the latest census was accomplished in 1985). The total population at the same time was 4 910 619 people, /19/. So, about 76% of the population lived in urban areas in 1985. An urban area was defined as an area where at least 200 people were living and where the maximum distance from one residence to another was 200 m. Assuming that 76% of the population still lives in urban areas and that Finland's population is 5 million, so, 3 800 000 people live in urban areas.

3. CALCULATION PRINCIPLES

3.1 CORROSION

Building materials

Real estate material denseness was estimated using material inventories carried out in the Stockholm area /21/. The corresponding figures for Finland were obtained by multiplying the quantity of material with the population ratio. The maintenance intervals included in the Swedish survey were used in order to find the area of different materials that have to be painted yearly in Finland. The resulting estimates were as follows : 4.3 mill. m^2 wooden windows, 4.4 mill. m^2 wooden facades, about 3.5 mill. m^2 zinc-coated steel roof and about 1.7 mill. m^2 plastering. In these calculations costs of total renewing were not considered, neither the better durability of new materials and paints.

Table 3.1. Painting costs of certain materials (the costs are obtained from painting agencies /12/) and the quantity of materials in Finnish urban areas that need reparation each year.

Material	FIM/m^2	mill. m^2	FIM mill.
Zinced roof	31.5	3.5	110.250
Plastered facade	54	1.7	110.500
Wooden facade	55	4.4	290.400
Wooden windows	69	4.3	296.700
Total		13.9	807.850

Costs caused by air pollution

Real estates

- Zinc-coated surfaces and painted galvanized steel: It is assumed that air pollution causes 40% of the damage, of which SO_2 causes 95%, or FIM 41.9 mill., and NO_x 5%, or FIM 2.2 mill.
- Plastered surfaces: Air pollution causes 40% of the damage, of which SO_2 causes 80%, or FIM 35.4 mill., and NO_x 20%, or FIM 8.8 mill.
- Painted wooden surfaces: Air pollution causes 40% of the damage, of which SO_2 causes 90% and NO_x 10% :
  Wooden facades: SO_2 FIM 104.5 mill., NO_x FIM 11.6 mill.
  Wooden windows: SO_2 FIM 106.8 mill., NO_x FIM 11.9 mill.

Other constructions

- Other zinc surfaces (7.9 mill. m^2). The dose-response $K = 0.22 \cdot SO_2 + 6.05$ is used /8/. FIM 30/m^2 in 1982 equals to about FIM 35/m^2 in 1989. The costs are calculated from (7.9 mill. m^2 · FIM 35/m^2) /(6 · t), where $t = 71/(0.22 \cdot SO_2 + 6.05)$. When SO_2 concentration is 15 $\mu g/m^3$ the costs are FIM 6.1 mill. This amounts to 95% of the costs caused by air pollution, NO_x emissions cause the remaining 5%, or FIM 0.32 mill.

Acidification of the groundwater

- Costs caused by acid ground water
- A survey carried out in Sweden in 1985 assumes that acid groundwater causes 15% of the damage in water supply systems (corrosion)
- The insurance companies in Finland paid FIM 230 mill. as compensation for water damage in 1987, whereas corrosion caused FIM 34.5 mill.
- 50% of the acidification of the ground is due to air pollution, of which 95% is due to SO_2 and 5% is due to NO_x
- 50% of the corrosion is due to acidification of the ground
- This implies that the cost of the damage caused by SO_2 is FIM 8.2 mill. and that caused by NO_x is FIM 0.43 mill.

The value of the corrosion damage caused by sulphur dioxide and nitrogen oxides in urban areas was FIM 340 mill. in 1989. The share of road traffic is in accordance with share of road traffic emission of pollutant concentrations:

Table 3.2. The cost of corrosion damage caused by sulphur dioxide and nitrogen oxides in urban areas in 1989 and the estimated share of road traffic of the damage, FIM million, %.

Surface	SO_2	NO_x
Zinc-coated roof	41.9	2.2
Plastered façade	35.4	8.8
Wooden façade	104.5	11.6
Wooden windows	106.8	11.9
Other zinc-surfaces	6.1	0.32
Water damage	8.2	0.43
Total, FIM million	303	35
Share of traffic of conc.	5%	60%
Damage caused by traffic	15	21

About 90% of corrosion damage is caused by SO_2 and about 10% by NO_x. The cost of corrosion damage caused by road traffic totals FIM 36 mill.

3.2 FOULING

In the United States a relationship between fouling costs (y, FIM/inhabitant) and particle concentrations (x, $\mu g/m^3$) was deducted during surveys in the 1970's. The costs are expected to increase linearly with the particle concentrations.

$y = [x/12\ \mu g/m3)] \cdot$ FIM 84.1/inhabitant

In Finnish urban areas particle concentrations (annual mean values) are 30 - 50 $\mu g/m^3$. Taking 40 $\mu g/m^3$ as an average, we get a cost for fouling that amounts to FIM 280 per inhabitant. With this figure as a reference it has been estimated that the cost caused by fouling is about FIM 200 per person in Finnish towns.

The population in Finnish towns and cities was about 2.75 mill. in 1989 (fouling is assumed to be a problem mainly in towns and cities). The annual cost caused by fouling is therefore 2.75 mill. · FIM 200 = FIM 550 mill.

The share of road traffic of particle concentrations in urban areas is about 75%. We assume that fouling is caused by particles only, which means that the share of road traffic causes 75% of the total costs. Exhaust gases and dust lifted up by the traffic are taken into account in the estimate.

Table 3.4. An estimate of the costs caused by the fouling impact of road traffic in 1989.

	SO_2	NO_x	O_3	HC	Particles
Damage					551
Share of traffic of conc.	5%	60%	-	90%	* 75%
Damage caused by traffic					413

Fouling is caused ≈ 100% by particles (SO_2 ≈ 0%). The cost of fouling damage caused by road traffic is altogether <u>FIM 410 mill.</u>

3.3 HEALTH IMPACT
3.3.1 CANCER

The number of cancer cases

In Sweden, about 28 000 new cancer cases are detected each year, of which 300 - 2 000 are estimated to be due to air pollution. The most likely number is 780.

Hydrocarbon emissions are 460 000 t/a (1988), of which 43% originates from road traffic.

A good third of the cancer cases caused by air pollution is due to hydro carbon emissions (a third of 780 is 260 and 40% is 312) /2/. Considering the carcinogenic affection of different components the share of road traffic was derived to be 360 out of 780, or 46%.

Considering the population rate, we would arrive at 150 - 1 000 cancer cases a year which are caused by air pollution in Finland, the most likely number being 400 a year.

The hydrocarbon emissions in Finland are 121 600 - 228 600 tonnes a year, of which the share of traffic is 40 700, which is about 20%. We assume that we can derive the number of cancer cases caused by air pollution Finland by taking the corresponding value in Sweden and multiplying it by the hydrocarbon emission rate. This results in (200 000 / 460 000) · 780, or about 340. Road traffic produces about 20% of all hydrocarbon emissions. In Sweden the figure is 43%. We assume that the road traffic share of carcinogenic compounds in Finland is half of that in Sweden. In Sweden, road traffic was concluded to cause 46% of air-pollution-caused cancer, which leads us to road traffic being responsible for 23% of air-pollution-caused cancer cases in Finland. We arrive at the conclusion that road traffic causes 80 cancer cases in urban areas in Finland each year.

Hospital treatment costs

- in 1987 there were 17 000 new cancer cases, and the hospital treatment costs totalled FIM 218 mill. in 1989
- we assume that the cases caused by road traffic are all lung cancer cases
- in 1987, there were 2 139 new lung cancer cases, or 12.6% of all cancer cases, the hospital treatment costs were about 12%, or FIM 26 mill.
- the average duration of lung cancer is 3.1 years
- during three years there will be 3 · 2 100 = 6 300 new cancer cases
- the treatment costs of one lung-cancer patient are FIM 26 mill. / 6 300 = FIM 4 100/case a year
- the treatment costs of the cases (80 cases) caused by road traffic are altogether 3.1 · FIM 4100 · 80 = FIM 1.0 mill.

Medicines

- Free medicines paid to patients suffering from "Malignant tumours", amounted to on average FIM 7 600 per patient entitled to compensation
- costs of cancers caused by road traffic : 80 · 3.1 · FIM 7 600 = FIM 1.9 mill.
- It is estimated that FIM 1.5 mill. will be outside hospital treatment. By adding the costs of medicines that are free to some extent, we reach a sum of about FIM 2 mill.

Daily sickness allowances

- FIM 88.6 mill. was paid to patients suffering from "Malignant tumours". There were 4 680 new sickness allowance periods. The above calculated 80 out of 4 680 is 1.7%, and we can therefore conclude that those cancer cases that road traffic causes cost FIM 1.5 mill. in allowances.
  In 2.1 years (out of a total of 3.1 years) the sum will amount to FIM 3.2 mill.

Disability pensions

- It is assumed that lung-cancer patients are entitled to disability pension during one year
- The average disability pension is FIM 3 700/month
- Total disability pension expenditure will amount to 80 · 12 · FIM 3 700/month = FIM 3.6 mill.

Production losses

- Of 80 cancer patients, 24 become ill at their working age (probabilities)
- The yearly average salary expenses during absence from work due to sickness is FIM 6 800 for an average employee. For those suffering from lung cancer we calculate FIM 15 000 a year (a factor of 2.25). Total costs caused by absence are about three times salary expenses, or 3 · 24 · FIM 15 000 = FIM 1.1 mill. making FIM 3.4 mill. in 3.1 years

Table 3.5. Estimation of costs of cancer caused by road traffic in urban areas in 1989, FIM million

	SO_2	NO_x	Pb	HC	Particles
Damage *		2.2		7.3	7,0
Share of traffic	5%	60%	100%	90%	75%
Damage caused by traffic		1.32		6.6	5,3

* : Differing from other corresponding tables, the damage caused by air pollution (first row) is calculated from the damage costs caused by road traffic. In other tables road traffic impacts have been calculated from the damage caused by air pollution knowing the share of road traffic of pollution.

The health impact (lung cancer) is caused by NO_x (10%), HC (50%), particles (40%). Costs caused by road traffic total FIM 13 mill.

3.3.2 RESPIRATORY DISEASES

Diseases in respiratory systems

- It is assumed that air pollution causes one fourth of all new cases.
  About 8 800 new patients are taken to hospital treatment in bed-wards annually. Air pollution causes 2 200 of these cases.
  Open care is yearly given to about 19 000 new patients, of which air pollution is the cause of one fourth, that is, 4 800.
- The estimates are based on an average duration of disease of four years

Costs of hospital treatment and open care

- The average treatment costs per ward patient is FIM 11 000, which with 2 200 patients in four years leads to total expenses of 4 · 11 000 · 2 200 = FIM 98 mill.
- Average treatment costs for patients receiving open care is FIM 1 000, expenses for 4 800 patients getting treatment will be 4 · FIM 1 000 · 4800 = FIM 20 mill.
- Total costs of hospital treatment of diseases in respiratory systems caused by air pollution amount to about FIM 120 mill. a year

Medicines

- The free medicines paid to patients suffering from "Malignant tumours" amounted to on average FIM 1 748 per person entitled to compensation a year (1989), from which we deduct the cost of medicines for patients in hospital treatment and we arrive at a cost of FIM 1 265
- Total costs of medicines will be 4 · (2200 + 4800) · FIM 1265 = FIM 35 mill.
- Taking into account medicines that are free to some extent, we reach a sum of about FIM 40 mill.

Daily sickness allowances

- In 1989 FIM 93.4 mill. was paid to patients suffering from "Diseases in respiratory systems". There were 31 720 new sickness allowance periods, divided among 24 400 different persons. It is assumed that the allowances are equally divided, in which case the patients were paid FIM 3 800 a year each
- During 3 years 2 200 patients in ward treatment were paid 2 200 · FIM 3 800 · 3 = FIM 25 mill.
- It is assumed that patients receiving open care treatment are capable of working

Disability pensions

- It is assumed that patients suffering from deseases in respiratory systems are entitled to disability pension during one year. Total disability pension expenditure will amount to 2 200 · 12 · FIM 3 700 = FIM 99 mill.
- It is assumed that patients receiving open care treatment are not entitled to disability pension

Production losses

- It is assumed that patients receiving open care treatment are capable of working and do not cause production losses
- It is assumed that the probability of becoming ill is the same during the whole lifetime, in which case the probability of becoming ill at an age interval of 16 - 62 is about 0.5. It can thus be concluded that 1 100 patients out of 2 200 of those that become ill will be at the age of 16 - 62.
- The yearly average salary expenses during absence from work due to sickness is FIM 6 800 for the average employee. For those suffering from diseases in respiratory systems we use FIM 15 000 a year (a factor of 2.25). Total costs caused by absence are about three times salary expenses, or 3 · 1 100 · FIM 15 000 = FIM 50 mill., or FIM 198 mill. in 4 years

Respiratory passage infections

- Respiratory passage infections cause absence from work on average 1.1% of working hours
- The costs caused by absence from work are about FIM 8 900/person, in which case absence due to respiratory passage infections cause a cost of FIM 98/person
- It is assumed that absence from work due to respiratory passage infections is an equally usual problem in all urban areas
- 76% of the population lives in urban areas (assumption: 76% of the labour as well). The total number of labour for 1990 was 2 448 800 people
- (0.76 · 2 448 800) · FIM 98 = FIM 182 mill.
- It is assumed that air pollution is the cause of 40% of the infections, in which case the costs amount to FIM 73 mill.

Total

- The costs of diseases in respiratory systems caused by air pollution total FIM 555 mill.
- The health impact (diseases in respiratory systems) is caused by SO_2 (35% of the cases), NO_x (20%), O_3 (5%), HC (5%) and particles (35%).
- The share of road traffic emission of total concentration is used to calculate the impact of road traffic (Table 2.6).

Table 3.6. Estimation of costs of diseases in respiratory systems caused by road traffic in urban areas in 1989, FIM million

	SO_2	NO_x	O_3	HC	Particles
Caused by air pollution cost of damage	190	110	28	28	190
Share of traffic of conc.	5%	60%	0%	90%	75%
Damage done by traffic	9.7	67	0	25	150

The health impact (diseases in respiratory systems) is caused by SO_2 (35% of the cases), NO_x (20%), O_3 (5%), HC (5%) and particles (35%). Costs caused by road traffic total FIM 250 mill.

3.4 FOREST DAMAGE

A Swedish report [3] assumes that some 20% of the needle and leaf damage is caused by SO_2, 30% by NO_x, 30% by O_3, 5% by HC and 10% by particles. Damage to the stand of forest is assumed to occur due to needle and leaf damage (50%) and acidification of the ground (50%). Acidification of the ground is up to 50% due to air pollution, the main pollutants being SO_2 (95%) and NO_x (5%). The share of different pollutants concerning forest damage are depicted in table 3.7.

Table 3.7. The share of different pollutants concerning forest damage

Pollutant	a = constant	Normalization	Approx.
SO_2	$10\,a + (95\,a)\cdot\frac{1}{4} = 33.75\,a$	46.6%	50%
NO_x	$15\,a + (5\,a)\cdot\frac{1}{4} = 16.25\,a$	22.4%	20%
O_3	15 a	20.7%	20%
HC	2.5 a	3.4%	3%
Particles	5 a	6.9%	7%

In a report published by IIASA in 1990, the economic value of forest damage caused by air pollution in Finland was estimated at USD 552.6 mill. a year (1987). This number includes the timber value and the value-added component by the primary forest products industry (incremental loss only). The loss is due to SO_2 and NO_x emissions.

If we assume that SO_2 and NO_x emissions cause altogether about 70% of the forest damage in Finland and that this amounts to USD 552.6 mill. according to IIASA, the total damage will be about USD 789.4 mill., which is about FIM 3 840 mill. (1989). This sum can be divided between different pollutants.

In order to find the share of Finnish road traffic, the estimates in table 2.5 have been used.

Table 3.8. Estimation of economic value of forest damage caused by road traffic emissions in 1989, FIM million

	SO_2	NO_x	O_3	HC	Particles
Damage	1921	768	768	115	269
Share of traffic	0.5%	11%	10%	20%	10%
Damage caused by traffic	9.6	84.5	76.8	23.0	26.9

Some 50% of the forest damage is caused by SO_2, 20% by NO_x, 20% by O_3, 3% by HC and 7% by particles. Costs caused by road traffic are altogether FIM 220 mill..

3.5 LOSS OF AGRICULTURAL CROPS

The value of 1989 field crops is depicted in table 2.9 /13/. The losses have been calculated using estimations from Sweden concerning the impacts of ozone on different plants /4/.

Table 3.9. Field crops, producers' price and estimation of losses caused by ozone in 1989

Species	Field crop value FIM million	Loss %	Loss FIM million
Fall-sown wheat	238.258	5.6	14
Spring wheat	1307.039	11	162
Fall-sown rye	593.530	13	89
Barley	2692.024	2.5	69
Oats	2495.666	11	308
Grass (hay)	2161.723	14	352
Potato	1093.629	19	257
Total	10581.869	10.6	1250

In the calculations it is assumed that ozone causes 50% of losses caused by air pollution. Total loss caused by air pollution were <u>FIM 2500 mill.</u> in 1989.

The shares of different pollutants have been estimated to be as follows : SO_2 20%, NO_x 20%, O_3 50%, HC 5% and particles 5%. The estimates in table 2.5 have been used in order to find the share of Finnish road traffic.

Table 3.10. Estimation of economic value of loss of agricultural crops caused by road traffic emissions in 1989, FIM million

	SO_2	NO_x	O_3	HC	Particles
Damage	500	500	1250	125	125
Share of traffic	0.5%	11%	10%	20%	10%
Damage caused by traff.	2.5	55	125	25	12.5

Loss of agricultural crops is caused by SO_2 (20%), NO_x (20%), O_3 (50%), HC (5%) and particles (5%). Costs caused by road traffic are altogether <u>FIM 220 mill.</u>

4. SUMMARY

The following table is a summary of costs calculated in this study that are caused by Finnish road traffic in Finland (mk, 1989).

The data on the damage caused by exhaust gases from 1989 has been surveyed. The costs presented are expressed in Finnish marks in the 1989 money value. The table presents for each impact the damage caused by each pollutant, FIM million.

The figure 0 means that the pollutant in question can be assumed to have some impact, but that the value of this impact expressed in marks is very small.

Table 4.1. The costs of damage caused by road traffic exhaust gases in Finland, FIM million (1989).

Pollutant :	CO_2	SO_2	CO	NO_x	Pb	HC	O_3	Part.	Total
Material damage altogether	0	15		21		0	0	410	450
- corrosion	0	15		21		0	0	0	36
- fouling		0						410	410
Diseases altogether	0	9.7	0	68	0	32	0	160	260
- cancer (lung cancer)		0		1.3	0	6.6		5.3	13
- respiratory systems		9.7		67	0	25	0	150	250
- diseases in cardiovascular system				0					0
Forest damage		9.6		85		23	77	27	220
Loss of agricultural crops		2.5		55	0	25	130	13	220
Total	0	37	0	230	0	80	210	610	1100

The literature used provided unexpectedly much data, on the basis of which it became possible to estimate an economic value of the damage caused by road traffic exhaust gases. It has, however, been necessary to make several assumptions in order to calculate costs. The valuation was made applying indirect methods, in which replacement costs, compensation costs and alternative costs are calculated. The reliability of the results depends on how accurately the dose-response relationship, the air quality level and the treshold level for damage beginning to take place have been established.

The total damage amounted to about FIM 1.2 billion a year, of which FIM 710 mill. marks originate from local impacts and FIM 440 mill. from nationwide impacts. For comparison, a survey made in Sweden can be mentioned, in which similar methods were used. According to this survey, exhaust gases caused damage at a local level to the value of SEK 520 - 1820 mill. a year (1982 money value). The ratio between damage costs at a local (urban) and pan-national level seems to be of the right magnitude. The big share of particles, on the other hand, seems to be overestimated. Also, ozone seems to get a surprisingly big share. Global impacts (global warming, destruction of the ozone layer etc.) have not been valued, since there are only some estimates of the extent and costs of these impacts.

In summary, although it has been possible to calculate many figures and costs, there is, however, great uncertainty about the correctness of these figures. Therefore, their use for estimating road traffic impacts can be recommended only in an experimental context. Knowledge of the impacts should improve considerably before more precise estimates of the value of the damage caused by road traffic emissions can be calculated.

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